BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

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SUBJECT: Launch Opportunities for AAP-1 Rendezvous with OWS at ∿35° Inclination - Case 610

DATE: May 22, 1969

FROM: I. Hirsch

NASW-417

ABSTRACT

Digital computer simulations of AAP-1 rendezvous opportunities show that the inclusion of an M = 16 CSM rendezvous mode increases the number of launch opportunities substantially over the case where rendezvous must be accomplished in four orbits or less.

Earth oblateness effects cause a small reduction in the launch vehicle performance along northerly launch azimuths compared with launches to the south. However, for a payload decrement of 200 pounds with respect to the southerly maximum capability, M = 16 launch opportunities to the north will exist on 50% of the days. The preponderance of M = 16 opportunities suggests that consideration should be given to making this mode the program baseline for CSM rendezvous.

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MEMORANDUM FOR FILE

I. Introduction

The AAP-2 flight will nominally place the orbital workshop (OWS) into a 185 x 210 nm orbit at approximately 35° inclination. The AAP-1 launch of the CSM is currently base-lined (Reference 1) to occur two days later and to rendezvous with the OWS. Nevertheless, the determination of subsequent launch opportunities is essential for building operational flexibility into the flight plans as well as for ascertaining the amount of payload capability which should be reserved for yaw steering and evaluating the efficiency of utilizing both northerly and southerly launch azimuths should the launch of AAP-1 be delayed.

A launch opportunity occurs when the position of the launch site meridian is such that the following two conditions can be simultaneously satisfied: (i) sufficient performance is available to fly a slightly doglegged trajectory to place position and velocity vectors in the same plane as the OWS orbit and (ii) the correct phasing between the CSM and OWS can be assured at initiation of the terminal phase maneuvers of the rendezvous. This memorandum presents the results of digital computer simulations made to determine when AAP-1 launch opportunities will occur. Range safety considerations as manifested in potential launch azimuth constraints will be seen to have an unfavorable effect on the southerly launch opportunities through condition (i) above.

The inclination of the OWS in this study was taken to be 35.93° to be consistent with recent MSFC data. Small variations in inclination will not substantially change the conclusions reached below.

II. Payload Decrement vs Yaw-Steering Capability

A launch window is defined in terms of the capability of the launch vehicle to maneuver into the target orbit plane with an appropriate yaw-steering program. Simulations were made with the Bellcomm AAP Simulator (References 2-3) to generate the yaw-steering programs and the corresponding payload data for targeting to specified orbital insertion conditions of flight path angle, insertion radius, inclination and descending node (measured in the equatorial plane from the launch site longitude at launch). Engine performance and stage weight data used in the simulations were obtained from References 4-7. A complete discussion of the relationship between targeted descending node and the amount of yaw steering required to put the CSM into the orbit plane of the OWS is contained in Reference 8 and will not be repeated here.

In targeting each run, second stage pitch angle and pitch rate were used to control altitude and flight path angle at cutoff; gravity turn kick angle was used to optimize payload; and launch azimuth and second stage yaw rate controlled cross-plane position and velocity errors at cutoff. A second stage initial yaw turn was not used because previous optimization studies had shown a zero value is very nearly optimum (Reference 8).

The upper part of Figure 1 shows payload decrement as a function of time (in minutes) from the center of a launch window, where the center corresponds to the zero yaw-steering program. There exist two zero-yaw trajectories to a 35.93° inclination orbit, one to the north and one to the south, with launch azimuths of 65.12° and 113.40° respectively. Payload decrement in Figure 1 is referenced to the maximum payload which can be inserted into an 81 x 120 nm orbit at 35.93° inclination with the SPS insertion technique. The relative optimums in payload for northerly and southerly launches of the CSM are seen in Figure 1 to differ by about 155 pounds. This difference results from the equatorial bulge of the Earth which contributes a perturbing acceleration during boost. This acceleration produces an additive component along the direction of the thrust acceleration for launches to the south but a negative contribution for northern launches. Payload capability figures in the AAP weight and performance reports are based on an optimum southerly launch to orbit without concern for range safety or rendezvous. Therefore, northerly launches impose a penalty of 155 pounds for the optimum case and somewhat more for a reasonable launch window.

III. Launch Azimuth Constraints

In Reference 8 it was reported that launch azimuths of 112° for 35° inclination orbits would bring the instantaneous impact point (IIP) plot of a CSM launch into close proximity of eastern regions of the West Indies. Launch azimuth can be restricted to a specified maximum value, but its role as a targeting variable must be replaced by another. An instantaneous yaw turn at the beginning of second stage operation is used, together with yaw rate through second stage, to satisfy the end point conditions of no cross-plane position or velocity error. One expects this procedure to be more costly of payload. Figure 1 shows the severity of this penalty for azimuth limits of 108°, 110° and 112°.

For launch window studies presented at the AAP Baseline Configuration Review on March 4, 1969, an azimuth constraint of 110° was assumed. In the ensuing discussion of launch opportunities this same upper bound on launch azimuths will be used.

IV. Phasing Considerations for Rendezvous

The in-plane launch window, determined by the amount of payload sacrificed for yaw steering, is only half the story. Launch must also occur within an in-phase launch window; that is, the central angle between chase vehicle and target must be within a range that allows the chaser to catch up at the end of the prescribed rendezvous maneuvers. It is most convenient to calculate in-phase windows independently. Then a launch opportunity exists whenever an in-phase window and an in-plane window overlap.

The duration of the in-phase window depends on how much the catch-up angle can be varied after launch. Since a satellite in a low orbit travels with faster angular speed than one in a high orbit, the catch-up angle is proportional to the product of orbit height difference and number of orbits spent there. The CSM is inserted onto an initial 81 x 120 nm orbit; near the end of rendezvous it must fly a coelliptic orbit 10 nm below the OWS, which is at 185 x 210 nm. In between, a parking orbit is used and its height can be chosen, in principle, anywhere between these two extremes in order to achieve the required catch-up angle. In fact, for this study, the phasing orbit height was assumed to lie between 120 x 120 and 165 x 190 nm. If M represents the number of orbits for the entire rendezvous, M-2 orbits will be spent in the parking orbit. The other two orbits will be consumed in the initial orbit, transferring out of the parking orbit, in the coelliptic coast, and in the final approach. In this study the M = 3, 4 and 16 rendezvous modes were studied since these are most compatible with operational constraints on ground tracking and crew activity timelines.

Terminal phase lighting is controlled by spending the proper amount of time in coelliptic coast prior to the terminal phase. Specific orbit geometry might require a change in coast time as much as ±1/2 orbit which would shift the calculated window ±12 seconds. This perturbation is negligible in comparison with the windows that do occur.

In-phase windows for the M = 3, 4 and 16 rendezvous were determined with the aid of a rendezvous simulation program described in Reference 9. The phase angle of the target vehicle corresponds to an OWS launch on Day 0 to the north with no yaw maneuvers. The in-phase windows covering a two week period following launch of the OWS are blocked in on the bottom portion of Figure 1. Because the M = 3 and M = 4 windows overlap and are of such short duration relative to the M = 16 windows, they have been combined in Figure 1 as M = 3/4 windows. A tabulation of the launch opportunities based on the data in Figure 1 is presented in Table I for several values of payload decrement with an azimuth constraint of 110° assumed to hold.

The M = 16 rendezvous is highly attractive in that it affords in-phase windows on the order of 35 minutes in length as compared with 1 or 2 minutes for an M = 3 or M = 4 rendezvous, thereby allowing many more launch opportunities. Table I illustrates the preponderance of launch opportunities for an M = 16 rendezvous. The M = 16 rendezvous has the added advantage of allowing the command module crew an opportunity for sleep following the busy pre-launch and launch activities schedule before they must perform the demanding rendezvous operations. During this time improved determination of the state vectors of the CSM and OWS can also be obtained.

The launch opportunity chart also shows that north and south opportunities are rather complementary; they rarely occur on the same day. Conversely, if either north or south launches are arbitrarily excluded, nearly half the opportunities disappear. Current plans call for only northerly launches. Nevertheless, opportunities occur on about half the days.

The number of launch opportunities is not terribly sensitive to the amount of payload set aside for yaw steering. The in-phase windows are long (35 minutes for M = 16) compared with the in-plane windows (7 minutes for 200 pounds, North), and the probability of overlap is not significantly increased by lengthening the in-plane window.

V. Nodal Regression

In doing an M = 16 rendezvous, the nodal regression cannot be neglected. Because the chase vehicle spends 14 of the 16 orbits in a circular phasing orbit as low as 120 nm as compared with the 185 x 210 nm orbit of the target vehicle, the difference in nodal regression rates is significant. In the worst case the difference in node angles between the OWS orbit and the CSM orbit would become approximately .25° over the 14 phasing orbits and would have to be corrected either by an in-orbit burn by the CSM of some 70 feet per second or by inserting the CSM on a suitably biased initial orbit plane. The latter alternative is more economical and can be easily implemented at launch.

VI. Conclusions

Inclusion of an M = 16 rendezvous mode for the CSM's in the mission planning will substantially increase the number of available launch opportunities for the AAP-1 rendezvous with the OWS. In fact, the M = 16 rendezvous mode so dominates the available opportunities that consideration should be given to simply baselining this option alone.

Assuming a reasonable payload decrement (say, 200 pounds) it appears that northerly launch opportunities exist on about 50% of the days. (For the OWS orbit parameters used in this study, the relation of in-phase to in-plane windows repeats roughly every eight days.) The southerly opportunities complement the northerly ones. That is, southerly launch opportunities generally exist on days when there is no northerly opportunity and there are extremely few days on which there is either no opportunity at all or an opportunity to launch either north or south.

Although a specific set of OWS parameters has been the basis for these conclusions, small variations in altitude or inclination will not affect the dominant role of the M = 16 rendezvous.

The author wishes to gratefully acknowledge the assistance of W. L. Austin in generating in-phase window data.

I. Hirsch

1025-IH-dcs I. Hirsch

Attachment

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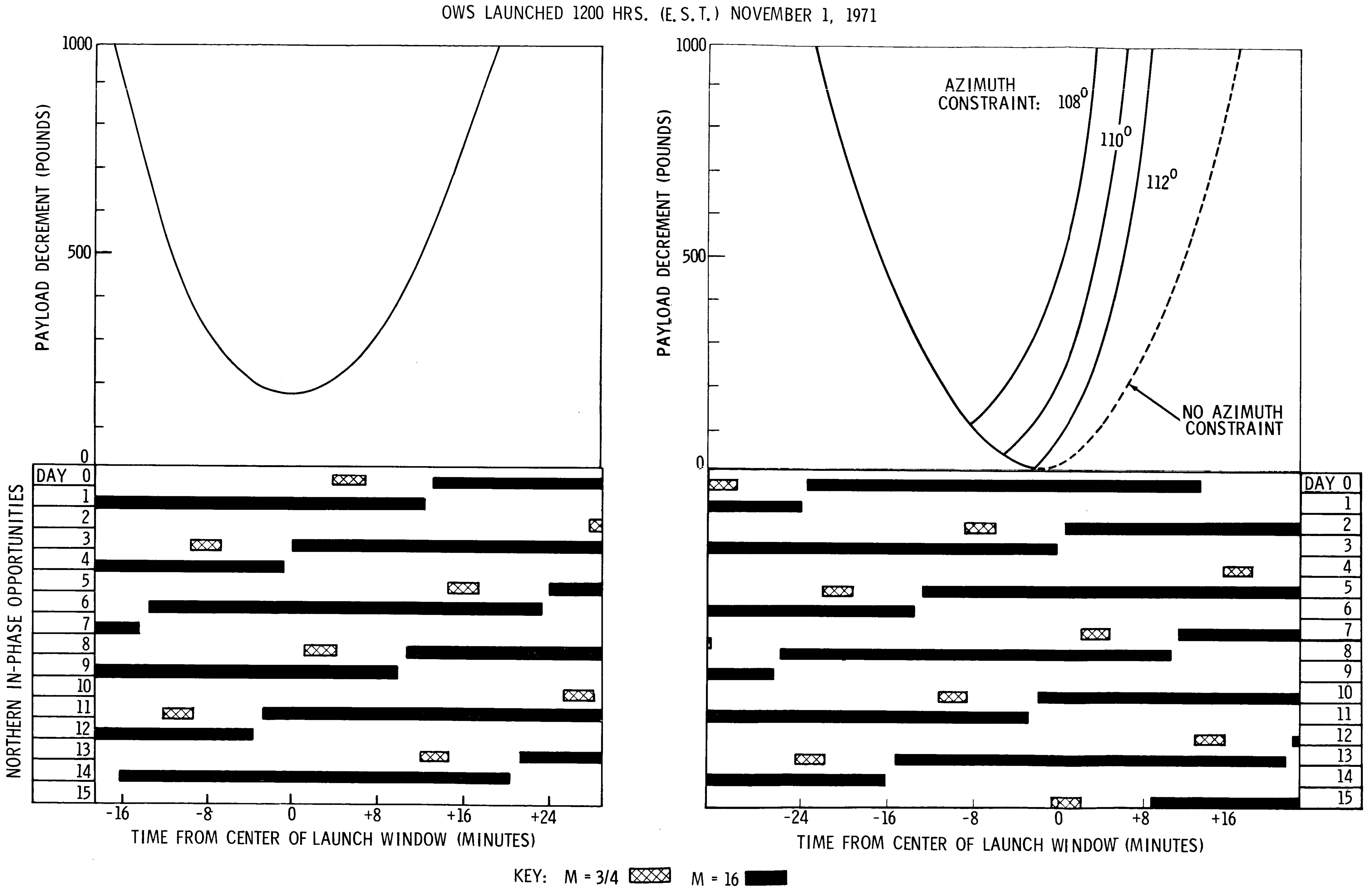

FIGURE 1 - NORTHERN AND SOUTHERN LAUNCH OPPORTUNITIES FOR AAP-1 RENDEZVOUS OF CSM WITH OWS AT 35.93^{0} INCLINATION.

PAYLOAD DECREMENT (pounds)	100				150				200				250			
	NORTH		SOUTH		NORTH		SOUTH		NORTH		SOUTH		NORTH		SOUTH	
M	3/4	16	3/4	16	3/4	16	3/4	16	3/4	16	3/4	16	3/4	16	3/4	16
DAY O				X				X	X			X	X			X
1										X				X		
2			X				X				X				X	X
3				X				X		X		X		X		X
4										X				X		
5				X				X				X				X
6										X				X		
7																
8				X				X	X			X	X			X
9										X				X		
10							X	X			X	X			X	X
11				X				X		X		X		X		X
12														X		
13				X				X				X				X
14										X				X		
15											X				X	

TABLE I

LAUNCH OPPORTUNITIES FOR VARIOUS VALUES OF PAYLOAD DECREMENT WITH A 110° LAUNCH AZIMUTH CONSTRAINT.

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Subject: Launch Opportunities for AAP-1 Rendezvous with OWS at $\sim 35°$ Inclination - Case 610

From: I. Hirsch

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